International Journal of Electrical and
Electronics Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278-943X
Vol. 4, Issue 2, Apr 2014, 47-58

TRANSIENT STABILITY IMPROVEMENT OF SCIG BASED WIND FARM WITH STATCOM

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ABSTRACT

Application of FACTS controller called Static Synchronous Compensator STATCOM to improve the transient stability in the presence of faults and the integration of new renewable source, like wind energy, these lasts make the electrical grid operate in a new condition .The essential feature of the STATCOM is that it has the ability to absorb or inject fastly the reactive power with power grid entirely by means of electronic processing of the voltage and current waveforms in a voltage source converter (VSC). This function is identical to the synchronous condenser with rotating mass. In the present work transient stability improvement using STATCOM under faults is proposed. Improvement of transient stability with and without STATCOM and reactive power injecting by a STATCOM is studied. Simulation results are given, commented and discussed. The test results prove the effectiveness of the proposed STATCOM controller in terms of fast damping the power system oscillations and restoring the power system stability.

KEYWORDS: Transient Stability, Active Power, Reactive Power, FACTS, STATCOM, Wind Farm

INTRODUCTION

With the increase in demand of power and decrease of fossil fuels, mankind has been forced to search alternative sources for the generation of electricity [1]. Nowadays wind as a significant proportion of non-pollutant energy generation, is widely used [2]. Wind power in spite of being stochastic in nature has proved itself as a viable solution to this problem. As the wind turbine technology is developing at a good pace, more and more wind power plants are being integrated with the conventional form of generation.

With the increase in the ratio of wind generation to conventional generation, several problems related with integration of wind farms have emerged [1]. In addition, power transmission and distribution systems face increasing demands for more power, better quality and higher reliability at lower cost, as well as low environmental effect. Under these conditions, transmission networks are called upon to operate at high transmission levels, and thus power engineers have had to confront some major operating problems such as transient stability, damping of oscillations and voltage regulation etc [3].These problems are due to distinct properties of the generators used with the conventional form (Thermal & Hydro) of generation and wind based generation. In thermal and hydro power based generation synchronous generators are used while in wind based generation mostly induction generators are used [1].

One of the simple methods of running a wind generating system is to use the induction generator connected directly to the grid system The induction generator has inherent advantages of cost effectiveness and robustness. However induction generators require reactive power for magnetization. When the generated active power of an induction generator is varied due to wind, absorbed reactive power and terminal voltage of an induction generator can be significantly affected [4].

Flexible AC Transmission Systems are represented by a group of power electronic devices. This technology was developed to perform the same functions as traditional power system controllers such as transformer tap changers, phase shifting transformers, passive reactive compensators, synchronous condensers, etc. Particularly FACTS devices allow controlling all parameters that determine active and reactive power transmission, nodal voltages magnitudes, phase angles and line reactance. Replacement of the mechanical switches by semi conductor switches allowed much faster response times without the need for limiting number of control actions. However, FACTS technology is much more expensive from the mechanical one. FACTS devices can be divided into two generations. Older generation bases on the thyristor valve, where newer uses Voltage Source Converters (VSC) [6].

Flexible AC Transmission Systems (FACTS) are used extensively in power systems because of their ability to provide flexible power control. Examples of such devices are the Static Synchronous Compensator (STATCOM) and the Unified Power Flow Controller (UPFC). STATCOM is preferred in wind farms due to its ability to provide bus bar voltage support either by supplying and/or absorbing reactive power in to the system [7].

The proposed STATCOM control scheme for grid connected wind energy generation for power quality improvement has following objectives.

- Unity power factor at the source side.
- Reactive power support only from STATCOM to wind Generator and Load.
- Simple bang-bang controller for STATCOM to achieve fast dynamic response [8].

WIND TURBINE MODEL

Squirrel Cage Induction Generator

The fixed speed wind generator systems have been used with a multiple-stage gearbox and a SCIG directly connected to the grid through a transformer. Therefore, rotor speed variations are very small, because the only speed variations that can occur are changes in the rotor slip, because the operating slip variation is generally less than 1%, this type of wind generation is normally referred to as fixed speed. A SCIG consumes reactive power. Therefore, in case of large wind turbines and/or weak grids, often capacitors are added to generate the induction generator magnetizing current, thus improving the power factor of the system as a whole. The slip is generally considered positive in the motor operation mode and negative in the generator mode. In both operation modes, higher rotor slips result in higher current in the rotor and higher electromechanical power conversion. If the machine is operated at slips greater than unity by turning it backwards, it absorbs power without delivering anything out i.e. it works as a brake [3]

The block diagram of wind turbine induction generator is shown in Figure 1. The stator winding is connected directly to the 60 HZ grid and the rotor is driven by a variable-pitch wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction generator speed must be slightly above the synchronous speed. The pitch angle controller regulates the wind turbine blade pitch angle β, according to the wind speed variations. A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle is kept constant at zero degree when the measured electric output power is under its nominal value. When it increases above its nominal value the PI controller increases the pitch angle to bring back the measured power to its nominal value. The pitch angle control system is illustrated in the Figure 2. [9]

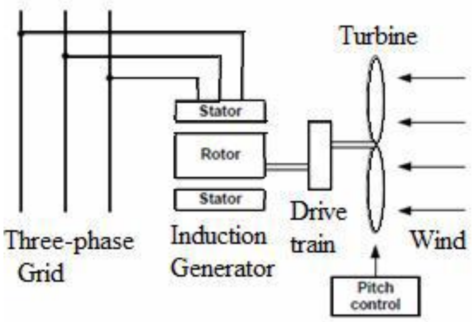


Figure 1: Wind Turbine Induction Generator

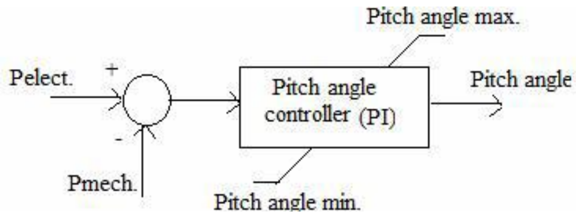


Figure 2: Control System for Pitch Angle Control

The model of wind turbine used for the purpose of simulation is a per unit model based on the steady state power equation of a wind turbine. The gear train used for coupling the generator with the grid is assumed to have infinite stiffness while the friction factor component and the inertia of the turbine is aggregated with these quantities of the electric generator coupled with the turbine [3].

$$P_m = C_p(\lambda,\beta)\frac{\rho A}{2}V_{wind}^{\ 3}$$

Here *Pm*= mechanical power developed by the wind turbine, *Cp*= power coefficient of the turbine, ρ is the density of air striking the turbine blades (kg/m3, A is the swept area of the rotor blades of the turbine (m2), λ is the tip-speed ratio, β is the pitch angle (degrees)[1,2,3,8,9].

$$C_p(\lambda,\beta) = c_1(\frac{c_2}{\lambda_i} - c_3\beta - c_4)\exp(-\frac{c_5}{\lambda_i}) + c_6\lambda_1$$

with

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

The relation between Cp, β and λ is shown in Figure 3.

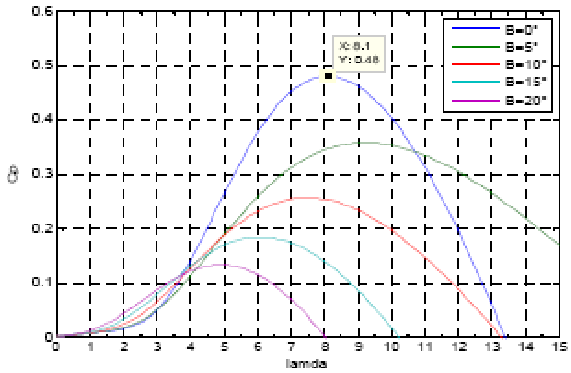


Figure 3: Aerodynamic Power Coefficient Variation Cp_ against Tip Speed Ratio λ and Pitch Angle β

Induction Machine

In the present study, the electrical part of the machine is represented by a fourth-order state-space model and the mechanical part by a second-order system. All electrical variables and parameters are referred to the stator. All stator and rotor quantities are in the arbitrary two-axis reference frame (d-q frame). The d-axis and q-axis block diagram of the electrical system is shown in Figures. 4 (a) and 4 (b) [9].

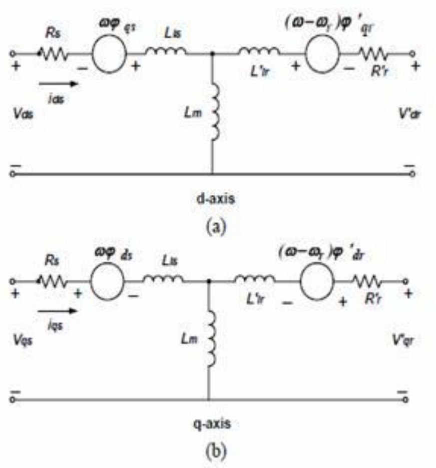


Figure 4: Induction Machine Equivalent Circuits (a) d-Axis Equivalent Circuit (b) q-Axis Equivalent Circuit

The electrical equations are given by:

$$v_{qs} = R_s i_{qs} + \frac{d}{dt}\phi_{qs} + \omega\phi_{ds}$$

$$v_{ds} = R_s i_{ds} + \frac{d}{dt}\phi_{ds} - \omega\phi_{qs}$$

$$v_{qr}^{'} = R_r^{'} i_{qr}^{'} + \frac{d}{dt}\phi_{qr}^{'} + (\omega - \omega_r)\phi_{dr}^{'}$$

$$v_{dr}^{'} = R_r^{'} i_{dr}^{'} + \frac{d}{dt}\phi_{dr}^{'} - (\omega - \omega_r)\phi_{qr}^{'}$$

$$T_e = 1.5p(\phi_{ds} i_{qs} - \phi_{qs} i_{ds})$$

Where

$$\phi_{qs} = L_s i_{qs} + L_m i_{qr}^{'}$$

$$\phi_{ds} = L_s i_{ds} + L_m i_{dr}^{'}$$

$$\phi'_{qr} = L'_r i'_{qr} + L_m i_{qs}$$

$$\phi'_{dr} = L'_r i'_{dr} + L_m i_{ds}$$

With

$$L_s = L_{ls} + L_m \text{ and } L'_r = L'_{lr} + L_m$$

The Mechanical Equations are given by

$$\frac{d}{dt}\omega_m = \frac{1}{2H}(T_e - F\omega_m - T_m)$$

$$\frac{d}{dt}\theta_m = \omega_m$$

STATCOM

Shunt compensators are primarily used for bus voltage regulation by means of providing or absorbing reactive power. They are effective for damping electromechanical oscillations. Different kinds of shunt compensators are currently being used in power systems, of which the most popular ones are Static Var Compensator SVC and STATCOM. In this work, only the STATCOM, which has a more complicated topology than SVC, is studied. The STATCOM is a FACTS controller based on voltage source converter VSC technology. A VSC generates a synchronous voltage of fundamental frequency and controllable magnitude and phase angle[2]. Static Synchronous Compensator (STATCOM) is a shunt controller mainly used to regulate voltage by generating/absorbing reactive power. The schematic diagram of STATCOM is shown in Figure 5.

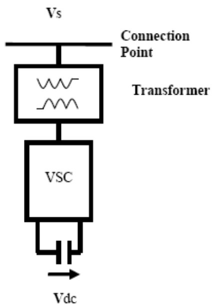


Figure 5: STATCOM

Operating Principle of STATCOM

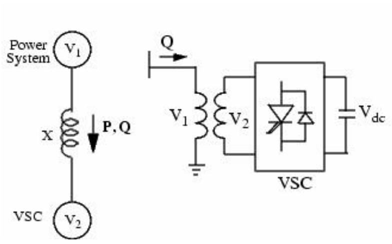


Figure 6: Operating Principle of STATCOM

The resulting STATCOM can inject or absorb reactive power to or from the bus to which it is connected and thus regulate bus voltage magnitudes. The main advantage of a STATCOM over SVC is its reduced size, which results from the elimination of ac capacitor banks and reactors; moreover, STATCOM response is about 10 times faster than that of SVC due to its turn-on and turn-off capabilities. The active and reactive power exchange between the VSC and the system is shown in Figure 6 are a function of the converter output voltage denoted as *Vout*, i.e.

$$P = \frac{V_1 V_2 \sin\delta}{X}$$

$$Q = \frac{V_1 (V_1 - V_2 \cos\delta)}{X}$$

Where

V1=line to line voltage of source V1

V2=line to line voltage of V2

X=Reactance of interconnection Transformer and filters

δ= angle of V1 with respect to V2

In steady state operation, the voltage V2 generated by the VSC is in phase with V1 (=0), so that only reactive power is flowing (P=0). If V2 is lower than V1, Q is flowing from V1 to V2 (STATCOM is absorbing reactive power).

On the reverse, if V2 is higher than V1, Q is flowing from V2 to V1 (STATCOM is generating reactive power). The amount of reactive power is given by

$$Q = \frac{V_1(V_1 - V_2)}{X}$$

A capacitor connected on the DC side of the VSC acts as a DC voltage source. In steady state the voltage V2 has to be phase shifted slightly behind V1 in order to compensate for transformer and VSC losses and to keep the capacitor charged.[9]

V-I Characteristics of STATCOM

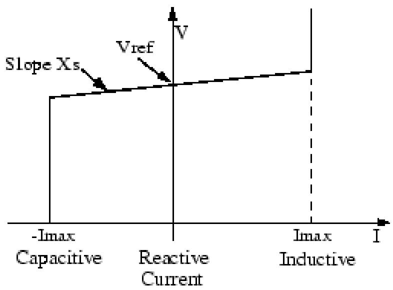


Figure 7: V-I Characteristics of STATCOM

As long as the reactive current stays within the minimum and minimum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure 7. In the voltage regulation mode, the V-I characteristic is described by the following equation:

V=Vref + Xs I

Where V: Positive Sequence Voltage (pu)

I: Reactive Current (I>0 indicates an Inductive Current)

Xs: Slope or Droop Reactance [10]

SIMULATION RESULTS

The proposed test system has three wind farms each having two equal wind turbines connected to a network of 2 bus bars. The type of generator is an Squirrel Cage Induction Generator (SCIG). Under normal operating conditions, the wind farm provide 9MW, the bank condenser used to offer a reactive power to the IG, as presents in the following Figure 8.

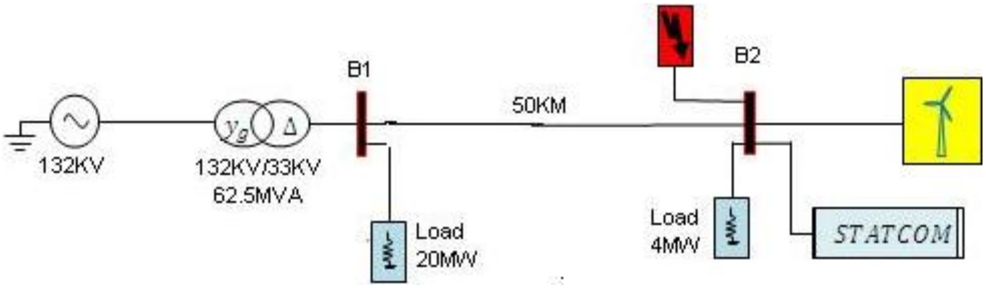


Figure 8: Test System

The first objective of this paper is to evaluate the specific needs of the system to restore to its initial state as quickly as possible after fault clearing.

Effect of Phase-Phase to Ground Fault on Wind Turbine2

The effect of a phase-Phase to ground fault at Wind Turbine2 is studied. The ground fault is initiated at t=15s and cleared at t=15.1s. The system is studied under different conditions at the load bus as chosen below.

Without STATCOM

Figure 9(a) and 10(a) shows the active and reactive power at the load bus, it can be seen that the active power curve reached 8.5MW in transient state operation and return near to zero in the steady state mode even with the presence of the fault, however a peak in the reactive power curve is found at the time of the application fault and stabilized at-2.2Mvar.

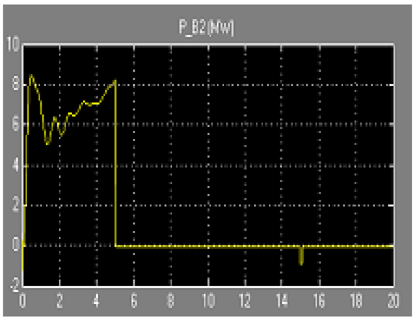
Figure 11(a) and 12(a) shows the active and reactive power of each wind turbine. It is clear according to these results that the active and reactive power of wind farm are disconnected before the appearance of fault, because of the insufficient condenser excitation of generator and the wind farm protection systems, however the reactive power gives a negative value because the presence of the condenser.

With STATCOM

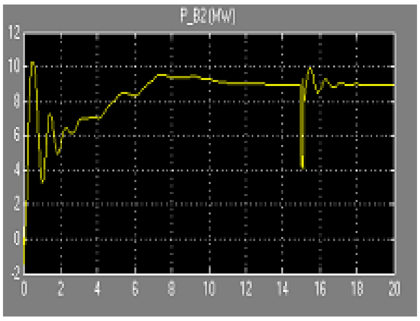
According to the previous simulation results, STATCOM at bus2 is added to view the STATCOM effects.

Figure 9(b) and 10(b) shows the active and reactive power at the load bus, it can be seen that in both the curves the active and reactive powers are stabilized faster with less oscillations compared with the preceding case in the transient state and even after the fault.

Figure 11(b) and 12(b) shows the active and reactive power for each wind turbine. According to the simulation results, the curves presented below shows the importance of the compensation when the wind farm recovers its operation after the fault and takes its stability with some oscillation by the intervention of STATCOM at bus bar 2.

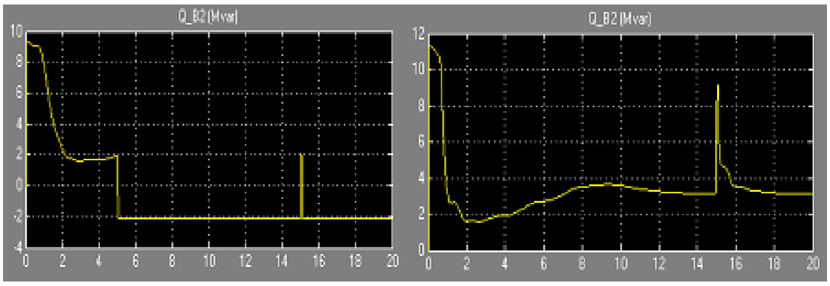


(a) Without STATCOM



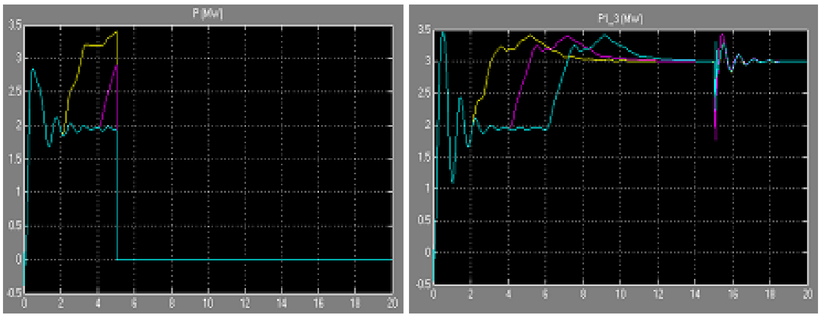
(b) With STATCOM

Figure 9: Active Power at 33kv Bus2



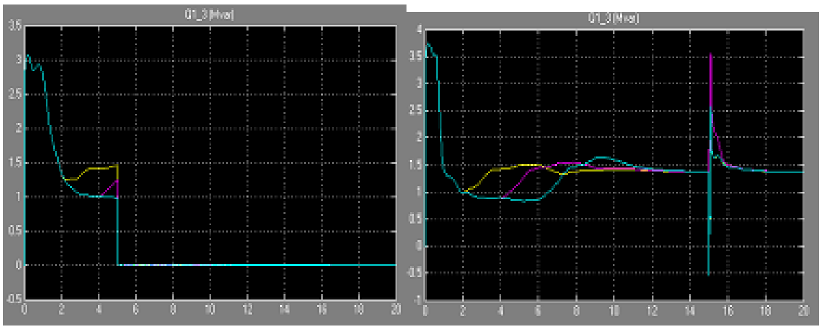
(a) Without STATCOM (b) With STATCOM

Figure 10: Reactive Power at 33kv Bus2



(a) Without STATCOM (b) With STATCOM

Figure 11: Active Power of Wind Farm



(a) Without STATCOM (b) With STATCOM

Figure 12: Reactive Power of Wind Farm

Effect of Three Phase to Ground Fault on Wind Turbine #2

Without STATCOM

Figure 13(a) and 14(a) shows the active and reactive power at the load bus, it can be seen that the active power curve reached 8.5MW in transient state operation and return near to zero in the steady state mode even with the presence of the fault, however a peak in the reactive power curve is found at the time of the application fault and stabilized at-2.2Mvar

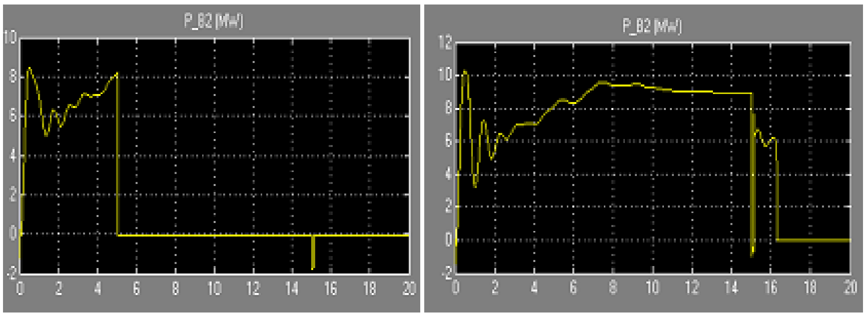
Figure 15(a) and 16(a) shows the active and reactive power of each wind turbine. It is clear according to these results that the active and reactive power of wind farm are disconnected before the appearance of fault, because of the insufficient condenser excitation of generator and the wind farm protection systems, however the reactive power gives a negative value because the presence of the condenser.

With STATCOM

According to the previous simulation results, STATCOM at bus2 is added to view the STATCOM effects.

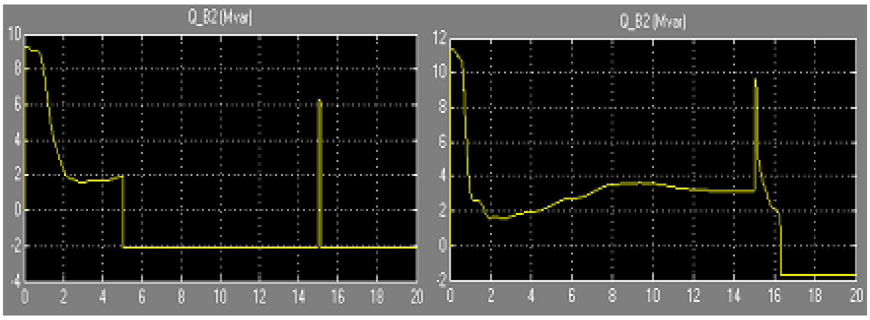
Figure 13(b) and 14(b) shows the active and reactive power at the load bus, it can be seen that in both the curves the active and reactive powers are stabilized faster with less oscillations compared with the preceding case in the transient state and even after the fault.

Figure 15(b) and 16(b) shows the active and reactive power for each wind turbine. According to the simulation results, the curves presented below shows the importance of the compensation when the wind farm recovers its operation after the fault and takes its stability with some oscillation by the intervention of STATCOM at bus bar 2.



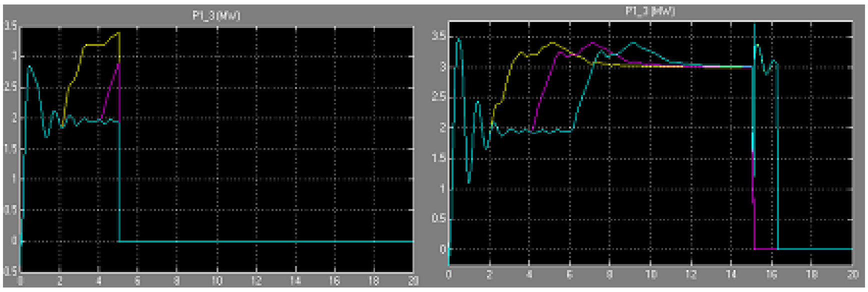
(a) Without STATCOM (b) With STATCOM

Figure 13: Active Power at 33kv Bus2



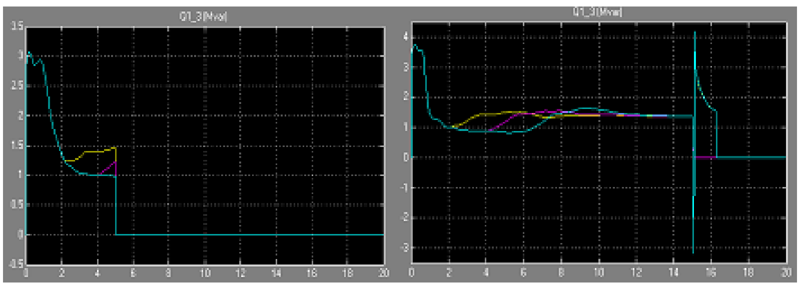
(a) Without STATCOM (b) With STATCOM

Figure 14: Reactive Power at 33kv Bus2



(a) Without STATCOM (b) With STATCOM

Figure 15: Active Power of Wind Farm



(a) With out STATCOM (b) With STATCOM

Figure 16: Reactive Power of Wind Farm

Figure 17 shows the Reactive Power supplied by STATCOM to the network

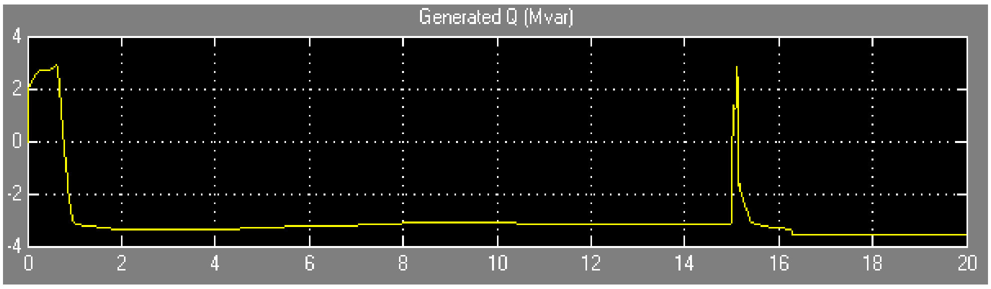


Figure 17: Reactive Power Injected by STATCOM

CONCLUSIONS

FACTS devices are power electronics based reactive compensators that are connected in a power system and are capable of improving the power system transient performance and the quality of supply. In this paper system stability of SCIG wind farms has been investigated. Power system with wind farms performance can be improved using FACTS devices such as STATCOM. The dynamic model of the studied power system is simulated using Simulink Matlab package sofware. Wind farm is compared with and without the presence of STATCOM under various faults like phase-phase to ground fault and three phase to ground fault. Test system contains three wind farms, each wind farm has two equal wind turbines. To validate the effect of the STATCOM controller of power system operation, the system is subjected to different disturbances such as faults and power operating conditions. The digital results prove the powerfulness of the proposed STATCOM controller in terms of stability improvement, power swings damping, voltage regulation, increase of power transmission and chiefly as a supplier of controllable reactive power to accelerate voltage recovery after fault occurrence.

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